Dry-Etching and Characterization of Facets for GaN-based Lasers

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For GaN lasers on sapphire substrates formation of smooth end facets remains to be challenging. Since GaN has a relatively low index of refraction (n=2.5), mirror reflectivity [$R_0 = (n-1)^2/(n+1)^2$] is only 18% at 410 nm wavelength even for a perfectly smooth facet. Furthermore, scattering losses reduce the facet reflectivity according to $R = R_0 \exp-\left(4\pi \cdot n \cdot \Delta d / \lambda\right)^2$ where Δd is the RMS roughness. Due to the short emission wavelength the surface smoothness requirements are more stringent for GaN lasers than that of near-IR lasers.

In principle cleaved facets are superior to their dry-etched counterparts since they reveal local rms roughness below 1 nm, which is a order of magnitude better than the values obtained for etched facets. Due to crystal orientation mismatch it is nearly impossible to obtain smooth and parallel mirrors by cleaving GaN on sapphire. For GaN lasers, SiC provides an alternative substrate with proper crystal orientation for cleaving. However, high tensile strain layers obtained for GaN layers grown on SiC makes cleaving difficult and might cause long-scale fluctuations. The resulting device-to-device variation in mirror quality complicates the analysis and optimization of other parameters such as geometry or processing. In contrast, typical etched facets display nm scale roughness resulting in reduction of reflectivity, in expense of providing better control of long-scale-homogeneity and repeatibility. Besides, etched mirrors allow for wafer scale fabrication of complete laser structures and the lasers can be potentially tested prior to cleaving. Also, mirrors with different geometries, such as corner reflector, can be fabricated by etching.

We report on formation and characterization of etched laser facets of (In,Al)GaN diodes grown on c-plane sapphire substrates. Since the epitaxial planes of device layers and substrates prevent cleaving of the facets, dry etching is used to fabricate the laser resonator. To succeed in vertical and smooth dry etched mirrors, there are strict requirements for the etch mask. In addition to the rquirements of high chemical and

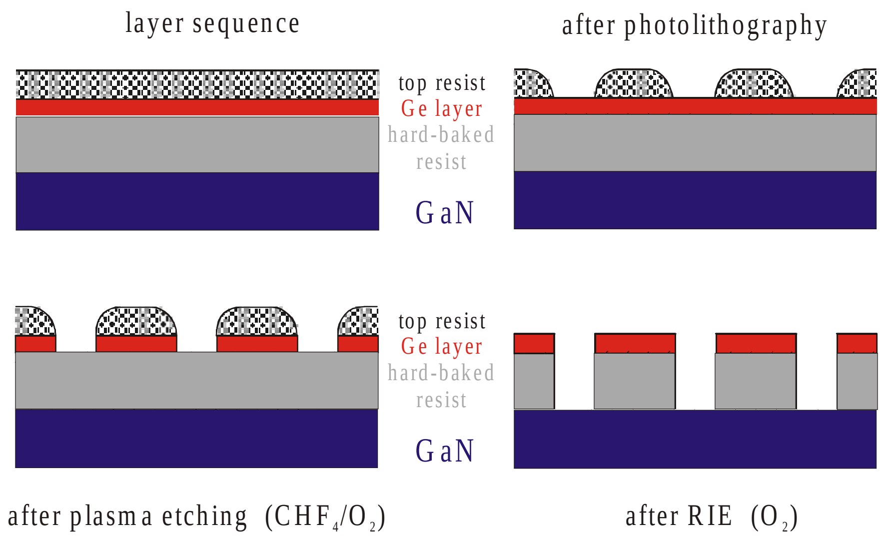

Fig 1: Schematic of different patterning steps using a trilevel resist for mirror etching

mechanical resistance, etch mask should have a vertical sidewall to prevent facet roughening by edge erosion during the etching process. Therefore, conventional AZ photoresist processes can easiliy result in striations on a micrometer scale, causing unsuitable facets. To circumvent this problem, we developed a trilevel resist process consisting of AZ4533 / Ge / AZ1512. The image layer formed by a positive resist, which is patterned by contact exposure. The pattern transfer on to the intermediate and bottom layer is achieved by CHF_3 /O_2 plasma etching and O_2 reactive ion etching (RIE), respectively (see Fig.1). In contrast to standard photoresist, the trilevel resist can withstand high ion energies and high temperatures without undergoing severe degradation. The resist pattern is transferred on to GaN using chemically assisted ion beam etching (CAIBE).

The etched laser facets are investigated using atomic force microscopy (AFM) and secondary electron microscopy (SEM). Figure 2 shows a SEM micrograph illustrating steep facets with an inclination angle of 1-4° for the trilevel resist process. Due to the low chemical etch rate in GaN , tilting the sample is essential to achieve the desired profiles. The structures defined by photolithography are free of large-scale riple.
In Fig. 3, AFM measurements show a RMS roughness of about 7 nm for a 2.5x2.5 µm area of the vertical sidewalls at around the active region. Due to the small inclination of the mirror, dry etching at the facets clearly reveals the defect structure of the material. This is indicated by the rod-like morphology observed in the AFM pictures of the facet. Additionally, slightly rounding takes place toward the top of the facet, which can be deduced from higher rod density. Optically pumped lasers reveal decent threshold excitation densities of about 600 kW/cm^2 for 400 µm long cavities.

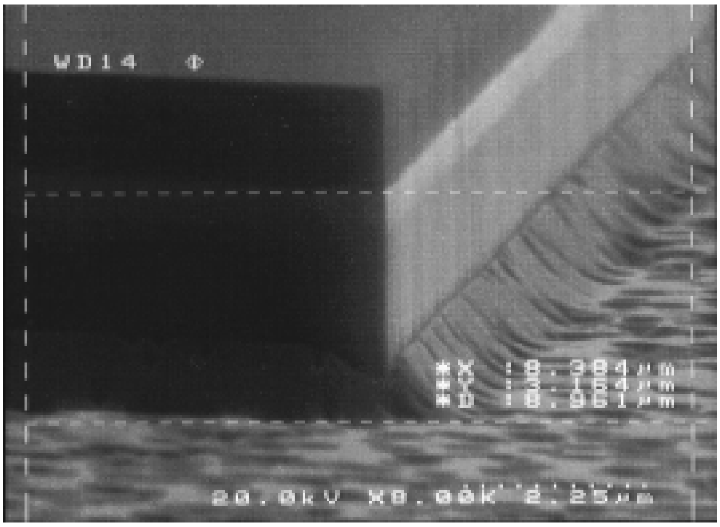

Fig.2: SEM micrograph of a dry etched laser facet. The inclination angle is about 4°.

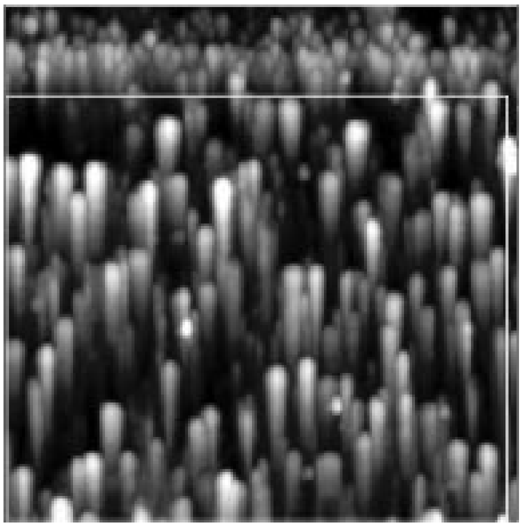

Fig.3: AFM micrograph of a dry etched facet. The depicted area is 2.5x2.5 µm. RMS roughness is about 7 nm.